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TITLE

METHOD AND APPARATUS FOR ELECTRO-BIOMETRIC IDENTITY RECOGNITION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional application 60/398,832, filed on July 29, 2002, and the entire disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to acquisition, processing, and analysis of electro-biometric signals. More particularly, the present invention relates to systems and methods for electro-biometric identification and verification of a person's identity.

[0003] The present invention provides a system and method for electro-biometric identification and verification of a person's identity by bioelectric signal acquisition, processing, and analysis.

[0004] Identity recognition plays an important role in numerous facets of life, including automatic banking services, e-commerce, e-banking, e-investing, e-data protection, remote access to resources, e-transactions, work security, anti-theft devices, criminologic identification, secure entry, and entry registration in the workplace.

[0005] Utilized alone or integrated with other technologies such as smart cards, encryption keys, and digital signatures, biometrics are expected to pervade nearly all aspects of the economy and our daily lives.

[0006] Computerized systems use passwords and personal identification numbers (PIN) for user recognition. To maintain security, passwords have to be changed on a regular basis, imposing a substantial burden on the users.

[0007] Several advanced technologies have been developed for biometric identification and verification of a person's identity, the leading of which are fingerprint recognition, retina and iris recognition, face recognition, and voice recognition. However, these technologies have penetrated only limited markets due to complicated and unfriendly acquisition modalities, sensitivity to environmental parameters such as lighting conditions and background noise, and high cost. In addition, due to complicated acquisition procedures, the above technologies usually require operator attendance.

[0008] Fingerprint recognition is well-established and the most mature technology, however it has several drawbacks: the system cannot verify physical presence of the fingerprint owner and therefore is prone to deception, limiting its suitability for on-line applications; the optical sensor is a costly and fragile device, generally unsuitable for consumer

markets; and it suffers from negative connotations related to criminology.

[0009] Retina scanning technologies are characterized by high performance. However, they require high-precision optical sensors, and are not user friendly as they require manipulation of head posture and operate on a very sensitive organ - the human eye. The optical sensor is costly and fragile.

[0010] Iris and face recognition systems are friendly technologies as they take an image from afar. However, they require digital photographic equipment and are sensitive to lighting conditions, as well as to pupil size variations and facial expressions, respectively. In addition, Iris recognition performance is degraded by dark glasses and contact lens usage, and face recognition may be deceived by impersonation.

[0011] Voice recognition is the most friendly technology, however it requires a low-noise setting and is highly sensitive to intrinsically variable speech parameters including intonation. Moreover, existing conventional recording technologies may be used to deceive speech based recognition systems.

[0012] Thus, a need exists for reliable and robust, hard to deceive (on-line and off-line), low cost, user friendly

identity recognition technologies for stand alone applications as well as for integration with current security systems.

BRIEF SUMMARY OF THE INVENTION

[0013] According to the invention an individual is identified by:

producing and storing a first biometric signature that identifies a specific individual by forming the difference between a representation of the heartbeat pattern of the specific individual and a stored representation of common features of heartbeat patterns of a plurality of individuals;

after the producing step, obtaining a representation of the heartbeat pattern of a selected individual and producing a second biometric signature by forming the difference between the heartbeat pattern of the selected individual and the stored representation of the common features of the heartbeat patterns of the plurality of individuals; and

comparing the second biometric signature with the first biometric signature to determine whether the selected individual is the specific individual.

[0014] The stored representation of common features of heartbeat patterns of a plurality of individuals can be obtained by measuring and storing such representations and

then averaging all of the stored representations, or employing techniques such as principal component analysis, wavelet decomposition, etc.

[0015] The individual can be a human or an animal.

[0016] Apparatus according to a preferred embodiment of the present invention performs automatic extraction of subject-specific bioelectric signals for the purpose of recognition of a person's identity. This apparatus can be incorporated into a wide range of devices and systems. A few non-limiting examples are: a smart card; a passport; a driver's license apparatus; a Bio-logon identification apparatus; a palm pilot; a cellular embedded identification apparatus; an anti-theft apparatus; an ECG monitoring apparatus, an e-banking apparatus, an e-transaction apparatus; a pet identification apparatus; a physical access apparatus; a logical access apparatus; and an apparatus combining ECG and Fingerprint monitoring. Other possibilities will be apparent to those skilled in the art.

[0017] Apparatus according to the invention can operate continuously or on demand. The apparatus can be constructed to obtain the representation of the heartbeat pattern of a selected individual by having electrodes that are contacted by either the hands or feet of the selected individual. When the apparatus of claim is provided in a smart card, the card can

be enabled for a limited period of time after successful recognition and disabled thereafter until the next successful recognition is performed. The apparatus can be constructed to operate with encryption keys or digital signatures.

[0018] According to one embodiment of the invention, the apparatus can be incorporated into a watch worn on the wrist, where the signal is measured between the wrist on which the watch is worn and the other hand of the wearer. The back side of the watch may be made of a conductive medium (*e.g.* a metal plate) in contact with the back of the wrist, and the face of the watch can be provided with another metal contact that needs to be touched with a finger of the other hand. The watch may transmit a signal indicating confirmation of the identity of its wearer, and/or activating a physically or logically locked device such as a door, a computer, a safe, etc. Alternatively, the watch may transmit personal information about its wearer.

[0019] A method according to a preferred embodiment of the present invention is based on electro-cardiologic signal discrimination. Analysis is carried out synchronously with the heart beat, eliminating features common to the general population and thus enhancing subject-specific features that constitute an electro-biometric, or biometric, signature, normally undetectable in raw electro-cardiologic signals.

[0020] The method according to the invention is based on acquisition of bioelectric signals, which are transformed into unique electro-biometric signatures. The uniqueness of the electro-biometric signatures makes the system very difficult to deceive, and its inherent robustness makes it ideal for local as well as for remote and on-line applications. In addition, the system is characterized by high recognition performance, supporting both open and closed search modes. An open search is one in which many stored signatures are searched to identify one subject, a closed search is one in which one stored signature is examined to verify the identity of one subject. An important advantage of the electro-biometric system according to the invention is its simple and straight-forward acquisition technology, implying a low-cost, user friendly acquisition apparatus and eliminating the need for a skilled operator.

[0021] The invention is based on a novel electro-cardiologic signal acquisition, processing, and analysis. Generally, electrical signals generated by the heart can be picked up using conventional surface electrodes, usually mounted on the subject's chest. The signals are made up of several components representative of different functional stages during each heart beat, projected according to the electric orientation of the generating tissues. Even a slight

change of electrode placement may cause drastic changes in the received signal morphology, to the extent of appearance or disappearance of distinct signal components.

[0022] The invention makes use of the fact that there exist electrode placement sites that produce subject-specific consistent signals, completely robust to changes of electrode placement within the sites. These sites are the arms and legs (including fingers and toes), which provide consistent, reproducible electro-cardiologic signals. The robustness to location variations in electrode placement within these sites stems from a constant electro-cardiologic signal projection which does not change as long as the electrodes remain close to a limb extremity.

[0023] Electro-cardiologic signals are affected by changes in pulse rate, which is a well-known electro-cardiologic modifier. Pulse rate changes may cause latency changes of the 'P' and 'T' components relative to the 'QRS' component of the electro-cardiologic signal (these components appear in Fig. 5). However, pulse rate changes may be automatically compensated for by retrospective, pulse rate driven adjustment of the signal complex. Moreover, an adaptive operation mode of the system can track and compensate for pulse rate induced changes. This can be done by compressing or expanding the time scale of one cycle of the heartbeat waveform. More

sophisticated formulation describing the relations between waveform characteristics (*e.g.* S-T, P-Q segment durations) and pulse rate may be used.

[0024] Different persons present subject-specific detail in their electro-cardiologic signals due to normal variations in the heart tissue structure, heart orientation, and electrical tissue orientation, which reflect on the electro-cardiologic signals measured from the limbs. However, in an electro-cardiologic signal, the subject-specific detail is obscured by major electro-cardiologic features that are common to the general population. Elimination of these common features, according to the invention, reveals subject-specific detail and allows for high-performance recognition of a person, using an identification signature derived from an electro-cardiologic signal as a unique bioelectric signature.

BRIEF DESCRIPTION OF THE DRAWING

[0025] Fig. 1 is a simplified block diagram of a system according to the invention, composed of a signal acquisition module, a signal processing module, and an output module.

[0026] Fig. 2 is a block diagram of an embodiment of the signal acquisition module of the system of Fig. 1.

[0027] Fig. 3 is a block diagram of an embodiment of the signal processing module of the system of Fig. 1.

[0028] Fig. 4 is a diagram showing a grand-average electro-cardiologic signal waveform, which may serve as a template, calculated from a database of 20 subjects.

[0029] Fig. 5 shows a group of electro-cardiologic signal waveforms of ten of the subjects participating in the database and contributing to the average waveform of Fig. 4.

[0030] Fig. 6 shows a group of electro-biometric signature waveforms, or templates, derived from the signal waveforms of fig. 5.

[0031] Fig. 7 shows a scatter plot and distribution histograms of the sign-maintained squared correlation values of the 20 subjects who contributed to the grand average waveform of Fig. 4.

DETAILED DESCRIPTION OF THE INVENTION

A preferred embodiment of a system according to the invention is designated an **E**lectro-**Bio**metric **ID**entification (E-BioID) system and is illustrated by way of example in Fig. 1. In this embodiment, the stored representation of the common features of the heartbeat patterns of the plurality of individuals is the average of the heartbeat patterns of the plurality of individuals. However, other embodiments can utilize stored representations of different types of common

features, such as attainable with, for example, principal component analysis or wavelet decomposition

[0032] In a preferred embodiment, the basic elements of the E-BioID system include a signal acquisition module 12, a signal processing module 14, and an output module 16, implemented in a single housing. In another preferred embodiment, remote analysis of locally acquired electro-biometric signals may be implemented by separating the functional elements for signal acquisition, processing, and output. Each of the components shown in Fig. 1 can be readily implemented by those skilled in the art, based on principles and techniques already well known in the art in combination with the present disclosure.

[0033] Fig. 2 shows a preferred form of construction of signal acquisition module 12 in an E-BioID system. The data acquisition module preferably includes a pair of sensors 22, pre-amplifiers 24, band-pass filters 26 and an analog-to-digital (A/D) converter 28. Each of these components can be readily implemented by those skilled in the art, based on principles and techniques already well known in the art in combination with the present disclosure.

[0034] Sensors 22 can be of any type capable of detecting the heartbeat pattern and can be, for example, metal plate sensors that can be connected as "add-on" onto a standard

computer keyboard. The subject need only touch the sensors with two fingers.

[0035] Fig. 3 shows preferred elements of signal processing module 14 in the E-BioID system. The signal processing module preferably includes a Digital Signal Processor (DSP) 32, a Dual Port Ram (DPR) 34, an Electrically Erasable Programmable Read Only Memory (E^2PROM) 36 and an I/O port 38. Each of these components can be readily implemented by those skilled in the art, based on principles and techniques already well known in the art in combination with the present disclosure. Signal processing module 14 is connected to signal acquisition module 12 and output module 16 via port 38.

[0036] In an alternative embodiment, the signal processing module may be implemented, with suitable programming, on a personal computer, which is a flexible computation platform, allowing straight-forward integration of the system into existing computing facilities in a home, office, or institute/enterprise environments.

[0037] Output module 16 preferably consists of a dedicated display unit such as an LCD or CRT monitor, and may include a relay for activation of an external electrical apparatus such as a locking mechanism. Alternatively, the output module may include a communication line for relaying the recognition result to a remote site for further action.

SIGNAL ACQUISITION, PROCESSING AND ANALYSIS

[0038] Bioelectric signals, or heartbeat signals, are acquired in a simple manner, where the subject is instructed to touch two metal plates 22 for a few seconds. The metal plates conduct the bioelectric signals to the amplifiers 24, which amplify the bioelectric signals to the desired voltage range. In a preferred embodiment, the voltage range is zero to five volts.

[0039] The amplified signals pass through filters 26 to remove contributions outside a preferable frequency range of 4Hz - 40Hz. Alternatively, a wider range of 0.1Hz - 100Hz may be used in conjunction with a notch filter to reject mains frequency interference (50/60Hz). Digitization of the signal is preferably performed with a 12-bit A/D converter 28, at a sampling frequency of preferably about 250Hz.

[0040] In module 14, the signals are normalized by the 'R' peak magnitude, to account for signal magnitude variations which mostly relate to exogenic electrical properties. The normalized data is transformed into an electro-biometric signature which is compared to pre-stored electro-biometric signature templates. The result of the comparison is quantified, optionally assigned a confidence value, and then transmitted to output module 16, which provides a recognition

feedback to the user of the E-BioID system and may also activate external apparatuses such as a lock or siren, virtual apparatuses like network login confirmation, or a communication link.

[0041] In another embodiment, the E-BioID system is implemented as a fully integrated compact device, where many of the functional elements are implemented on an ASIC based system.

PRINCIPLE OF OPERATION

[0042] Biometric recognition requires comparing a newly acquired biometric signature against templates in a registered or enrolled biometric signature template database. This calls for two phases of operation of the system: Enrollment and Recognition.

ENROLLMENT PHASE

In a preferred embodiment, each new subject is instructed to touch two metal plates with two fingers, one of each hand. In alternative embodiments, the subject may touch the metal plates with other parts of the hands or legs. The system monitors the subject's pulse rate and initiates a recording, preferably lasting for at least 20 seconds. Shorter intervals may be used depending on the required level of accuracy. Once

the recording is complete, the system performs a self-test to verify signature consistency by comparison of at least two biometric signatures, derived from two parts of the registered segment. The two parts may be two halves, or two larger, overlapping, segments. The two parts are used to derive two biometric signatures. If the self-test result is successful, enrollment of that subject is complete, and if unsuccessful the procedure is repeated. The successful recording is used for construction of an electro-cardiologic signal or a series of electro-cardiologic signals, which are added to an electro-cardiologic signal database.

[0043] The electro-cardiologic signals are transformed into a set of electro-biometric signature templates by eliminating features that are common to all of the subjects participating in the dataset, thereby enhancing subject-specific discriminating features.

[0044] In a preferred embodiment, the system creates a grand-average electro-cardiologic template, which is calculated by synchronous averaging of the normalized electro-cardiologic signals of the entire pool of subjects. The grand-average represents the above-mentioned common features, and thus subtraction of the grand-average from each one of the electro-cardiologic signals yields a set of distinct, subject-specific electro-biometric template signatures. In an

alternative embodiment, other means for elimination of the common features may be used, such as a principal component analysis or wavelet decomposition.

[0045] In another preferred embodiment, the database is divided into several subsets, so as to maximize intra-subset similarity and inter-subset disparity, yielding several distinct grand-averages. The partition into subsets may be performed using standard pattern classification schemes such as linear classifiers, bayesian classifiers, fuzzy classifiers, or neural networks. The partition into subsets is useful in cases of large databases, to simplify and shorten the search process as well as to ensure the validity of the grand-average as an appropriate representative of similarity among the electro-cardiologic signals.

[0046] Fig. 4 shows an example of a grand-average, constructed from a pool of 20 subjects participating in the database.

[0047] Fig. 5 shows 10 examples of electro-cardiologic signals, and Fig. 6 shows the electro-biometric template signatures derived from the above electro-cardiologic signals, by elimination of features common to all the subjects included in the database. Specifically, each signature of Fig. 6 is obtained by subtracting the waveform of Fig. 4 from the corresponding signal of Fig. 5. It will be observed that

while the original electro-cardiologic signals are highly similar, the derived electro-biometric signatures present markedly pronounced differences. These differences have been found to reflect inherently unique electro-cardiologic disparity which underlies the recognition capabilities of the E-BioID system.

RECOGNITION PHASE

[0048] In the recognition phase, the subject interacts with the system in a similar manner to that of the enrollment phase, however a shorter recording time in the order of a few seconds is sufficient.

[0049] In a preferred embodiment, the system executes a verification procedure (closed search): the system processes the acquired signals, forms an electro-biometric subject signature, adjusts the signature according to the pulse rate, and compares the adjusted electro-biometric signature with the subject's enrolled electro-biometric signature template.

[0050] In another preferred embodiment, the system executes an identification procedure (open search): the system repeats the comparison process for the entire or partitioned database, thereby providing identification of the matching identity.

THE COMPARISON PROCESS

[0051] In a preferred embodiment, the comparison is performed by calculation of a correlation coefficient, ρ, between an electro-biometric signature σ_j and an electro-biometric signature template Φ_i, as follows:

$$\rho = \frac{COV\lfloor \sigma_{j,} \Phi_i \rfloor}{\sqrt{VAR\lfloor \sigma_j \rfloor \cdot VAR\lfloor \Phi_i \rfloor}}.$$

[0052] The correlation coefficient is squared, maintaining its original sign: $\eta = sign(\rho) * |\rho|^2$. In an alternative embodiment, the comparison may be based on other similarity measures, such as RMS error between electro-biometric signatures.

[0053] The comparison may yield one or several correlation coefficients, depending on the mode of operation: closed search; or open search. In a closed search mode, the sign-maintained squared correlation coefficient (η) is used for making the recognition decision: a value greater than a preset threshold is regarded as a positive identification, or a match; borderline, near-threshold values may indicate a need for extended or repeated recording. In an open search mode, the largest sign-maintained squared correlation coefficient among all sign-maintained squared correlation coefficients

yields the most likely subject identification, provided that the highest coefficient is above a selected threshold.

[0054] The preset threshold is derived from the required confidence level; higher desired confidence levels require higher thresholds. In one embodiment, sign-maintained squared correlation values larger than 0.8 are characteristic of a match and values lower than 0.7 are characteristic of a mismatch. Thus, sign-maintained squared correlation values higher than 0.8 may be considered as true matches and values lower than 0.7 as mismatches.

[0055] The upper diagram of Fig. 7 shows a scatter plot of sign-maintained squared correlation values, marking the 0.8 threshold with a dashed line. A clear separation between matches (circles) and mismatches (stars) is evident. The histograms in the other two diagrams provide a different view of the powerful recognition capabilities of the E-BioID system, where it can be seen that the mismatches are concentrated around the zero value (no correlation) while matches are densely distributed near 1.0 (absolute correlation).

[0056] In alternative embodiments, more sophisticated decision schemes may be used such as multi-parameter schemes (e.g. fuzzy logic schemes), which use more than one distance

measure; for example, multiple correlation values can be derived from segmented data analysis.

[0057] In a preferred embodiment, the system improves its performance with time by adding electro-cardiologic signals to the subject's database file when changes in the signals are encountered. In subsequent recognitions, the system processes the newly acquired signals, calculates the pulse rate, forms an electro-biometric subject signature, selects the enrolled electro-biometric signature template with the most similar pulse rate, and compares the new electro-biometric signature with the selected enrolled electro-biometric signature template.

[0058] In another preferred embodiment, the system uses signals acquired during long-term system operation to track possible variation in the enrolled subject electro-cardiologic signal, and if consistent changes occur the enrolled signal is automatically adjusted to reflect these changes. This tracking process compensates for gradual changes in the electro-cardiologic signal over long time periods, but does not compensate for fast, acute changes like those expected in connection with clinical heart conditions. In another embodiment, such acute changes may be reported to the subject indicating a need for medical consultation.

EXAMPLE: ENROLLMENT ALGORITHM

[0059] The following is an example algorithm for the enrollment phase:

i. Let $x_i(n)$ represent a 20-second, 250Hz digitized sample of the i^{th} new subject, where n denotes discrete units of time.

ii. $x_i(n)$ is band-pass filtered in the range 4Hz - 40Hz.

iii. The filtered signal is denoted $y_i(n)$.

iv. The filtered signal $y_i(n)$ is searched for QRS complexes, identifying the 'R' peaks as anchor points.

v. The filtered signal $y_i(n)$ is maintained or inverted to obtain positive 'R' peaks.

vi. The identified QRS complexes are counted to establish an average pulse rate reading PR_i.

vii. The filtered signal $y_i(n)$ is segmented around the anchor points, taking 50 samples before and 90 samples after each 'R' anchor point.

viii. Each data segment is normalized by the amplitude of the 'R' anchor point.

ix. The segments are aligned around the anchor points and averaged to produce the subject electro-cardiologic signal, denoted $s_i(n)$.

x. The subject electro-cardiologic signal $s_i(n)$ is adjusted according to the average pulse rate PR_i, by normalizing 'P' and 'T' latencies according to the pulse rate. The adjusted electro-cardiologic signal is denoted $v_i(n)$.

xi. The pulse rate adjusted subject's electro-cardiologic signal $v_i(n)$ is added to the database and is introduced into a grand-average $T(n)$.

xii. A set of electro-biometric signatures Φ_i is constructed by subtraction of the grand-average $T(n)$ from each of the pulse rate adjusted electro-cardiologic signals stored in the system database.

EXAMPLE: RECOGNITION ALGORITHM

[0060] The following is an example an algorithm for the recognition phase:

i. Let $x_j(n)$ represent a 10-second, 250Hz digitized sample of the tested subject.

ii. $x_j(n)$ is band-pass filtered in the range 4Hz - 40Hz.

iii. The filtered signal is denoted $y_j(n)$.

iv. The filtered signal $y_j(n)$ is searched for the locations of QRS complexes, using the R peak as an anchor point.

v. The filtered signal $y_j(n)$ is maintained or inverted to obtain positive 'R' peaks.

vi. The identified QRS complexes are counted to establish an average pulse rate reading PR_j.

vii. The filtered signal $y_j(n)$ is segmented around the anchor points, taking 50 samples before and 90 samples after each anchor point.

viii. The segments are aligned around the anchor points and averaged to produce the subject electro-cardiologic signal, denoted $s_j(n)$.

ix. The subject electro-cardiologic signal $s_j(n)$ is normalized according to the average pulse rate PR_j. The pulse rate adjusted subject electro-cardiologic signal is denoted $v_j(n)$.

x. An electro-biometric signature σ_j is constructed by subtraction of the grand-average $T(n)$ from the pulse rate adjusted electro-cardiologic signal $v_j(n)$.

xi. The correlation coefficients between the electro-biometric signature σ_j and all the enrolled electro-biometric signatures Φ_i are calculated and squared, maintaining their original arithmetic sign.

xii. The largest sign-maintained squared correlation value is selected and compared to a preset threshold.

xiii. If the selected largest sign maintained squared correlation value is larger than the preset threshold then a positive match is indicated, and the subject is identified.

[0061] Thus, a method and apparatus of acquisition, processing, and analysis of electro-cardiologic signals for electro-biometric identity recognition may include any subset of the following enrollment and recognition steps:

ENROLLMENT

[0062] Acquisition, digitization, and storage of electro-cardiologic signals from subjects;

a. Formation of an electro-cardiologic signal database;
b. Partition of the template database into several subsets based on electro-cardiologic signal similarity;
c. Construction of one or more grand averages;
d. Derivation of subject-specific electro-biometric signatures.

RECOGNITION

VERIFICATION

[0063] The newly captured electro-biometric signature is compared with the subject specific enrolled electro-biometric signature template;

e. Correlation and confidence analysis of the newly captured subject electro-biometric signature with the relevant stored electro-biometric signature template;

f. Display and registration of the recognition result and/or activation of a physical or virtual local/remote mechanism.

IDENTIFICATION

[0064] The newly captured electro-biometric signature is compared with all of the electro-biometric signature templates participating in the database;

g. Correlation and confidence analysis of the newly captured subject electro-biometric signature with all stored electro-biometric signature templates;

h. Display and registration of the recognition result and/or activation of a physical or virtual local/remote mechanism.

[0065] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without undue experimentation and without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be

comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. The means, materials, and steps for carrying out various disclosed functions may take a variety of alternative forms without departing from the invention.

[0066] Thus the expressions "means to..." and "means for...", or any method step language, as may be found in the specification above and/or in the claims below, followed by a functional statement, are intended to define and cover whatever structural, physical, chemical or electrical element or structure, or whatever method step, which may now or in the future exist which carries out the recited function, whether or not precisely equivalent to the embodiment or embodiments disclosed in the specification above, i.e., other means or steps for carrying out the same functions can be used; and it is intended that such expressions be given their broadest interpretation.